BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 08018

SUBJECT: Effect of Space Shuttle Booster First vs Orbiter First Development on Booster Contingency Oversizing
Case 105-6

DATE: August 11, 1970

FROM: D. E. Cassidy

ABSTRACT

Developing the Space Shuttle booster before the orbiter could require a considerably larger booster than would be necessary if the orbiter were developed first. To guarantee a fixed payload, the booster would have to be developed about 25% larger in gross weight and engine size to provide a 10% inert weight contingency factor in both the booster itself and in the delayed orbiter. This would compare with a booster oversize of about 6% to compensate for just the booster inert weight growth if the orbiter were previously developed to its nominal weight. For a potential 20% inert weight growth, the booster oversize would be about 50% and 12% for the booster first and orbiter first developments respectively.

A larger booster than necessary would increase the cost of developing and operating the eventual fully reusable Space Shuttle, and could limit the Space Shuttle operational utility.

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MEMORANDUM FOR FILE

INTRODUCTION

It may be necessary to delay the development of the fully reusable two stage space shuttle. A low level of available space vehicle development funding as well as the uncertainties involved in reusable launch vehicle technology and system design could necessitate developing either the orbiter or booster first instead of the simultaneous development presently under study by the NASA and the NASA contractors.[1]

If the reusable orbiter were developed first, an SIC or a new low cost expendable booster could be used to launch the reusable orbiter until the reusable booster was developed.[2] Alternatively, the reusable booster could be developed first and used to launch an expendable second stage (SIVB, SII, or a new stage) plus payload until the reusable orbiter is available.[3,4]

The advantages of developing either the orbiter or booster first will involve the consideration of a number of factors. The relative operational utility of the interim system, the impact of interim requirements on the final system design and utility, and the relative costs will determine the best approach. Since system size and weight are significant factors in determining airframe and engine development costs, operational costs and operational utility, the relative inert weight sensitivity involved in developing either the booster or the orbiter first is an important consideration.

The purpose of this memorandum is to point out the relative weight sensitivities involved in the two approaches with emphasis on the required booster oversize*

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*Booster oversize is defined here as the booster size (weight and engine size) in excess of the best estimated size without inert weight contingencies.

necessary to guarantee 25,000 pounds of payload with the eventual fully reusable system. It will be shown that for the same contingency factors on inert weight, the booster may have to be oversized substantially more in the case of the booster first compared to the orbiter first development.

ESTIMATED SPACE SHUTTLE DESIGN CURVES

The data points without subscripts on Figures 1 and 2 were derived from the recent Integral Launch and Reentry Vehicle (ILRV) studies.[5,6] The subscripted data points were derived from contractor proposals for the space shuttle phase B studies[7,8] submitted in response to the NASA request for proposal.[1]

These data show a rough correlation between the propellant stage fractions and gross stage weights for the reusable orbiter and booster. The square symbols in Figures 1 and 2 correspond to a representative reference design point with a gross lift off weight of 3.5 million pounds and payload of 25,000 pounds. The dashed curves are extrapolated from the reference point and are used to estimate the changes in propellant stage fraction with stage weight that might be expected from the trend of the ILRV data. In the case of the orbiter, a spread is used to account for the large differences in the available data.

EFFECTS OF SPACE SHUTTLE INERT WEIGHT GROWTH

The booster size necessary to compensate for increases in the orbiter inert weight is presented in Figure 3. It is assumed here that the inert weight of the orbiter increased during development but the orbiter propellant was fixed (i.e., fixed design) so that the booster must be increased in size to hold the payload constant. The estimated booster design curve was derived from the λ' vs booster gross weight correlation on Figure 1. The limit lines are included on Figure 3 to illustrate the maximum and minimum possible booster weight variation. The minimum limit line (top line) is based on the assumption that it is not possible to increase the booster size with a fixed inert weight. The maximum limit line (bottom line) assumes that the stage fraction (λ') will not decrease with increased size.

If the orbiter were developed first it is reasonable to conclude that the booster could be sized to make up for changes in the orbiter inert weight. The booster might have to be considerably larger than the nominal if the orbiter inert weight grew during development, but this would be determined after the orbiter was built and would not have to be included as a contingency in the booster design.

On the other hand, if the booster were developed first with fixed propellant capacity, it might not be possible to size the orbiter sufficiently large to compensate for booster inert weight growth unless the booster was initially oversized. This is illustrated on Figure 4. The solid lines represent the nominal booster performance curves with inert weights varying from zero to 30% higher than nominal. If the orbiter design band from Figure 2 is superimposed on the booster performance curves, only the high λ' side of the band falls below the nominal booster curve. In order to compensate for booster inert weight (i.e., the orbiter curve must intersect the booster curve corresponding to the appropriate inert weight growth), it would be necessary for the propellant stage fraction of the reusable orbiter to increase more rapidly with increasing stage weight than is indicated in Figure 2. It seems, at best, that an unreasonably large orbiter would be necessary to compensate for only small booster inert weight growth.

REUSABLE BOOSTER CONTINGENCY OVERSIZING

In either case, the reusable booster would have to be oversized to provide contingency for inert weight growth. The amount of booster oversize necessary to compensate for potential orbiter and booster inert weight growth is summarized in Figure 5. The upper two curves represent the contingency for both orbiter and booster inert weight growth which must be built into the booster if the booster is developed first. The lowest curve represents the contingency which must be built into the booster to account for only the booster growth assuming the orbiter is already built to its nominal weight. For these two cases the resulting booster oversize contingency would be about 25% and 6% respectively to compensate for a potential 10% inert weight growth or about 50% and 12% to compensate for a 20% inert weight growth.

Developing the orbiter first appears to offer the most potential for minimizing the Space Shuttle weight. Further study would be required, however, to assess the extent of the interim expendable booster design requirements on the reusable orbiter weight.

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Attachments
Figures 1-5

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REFERENCES

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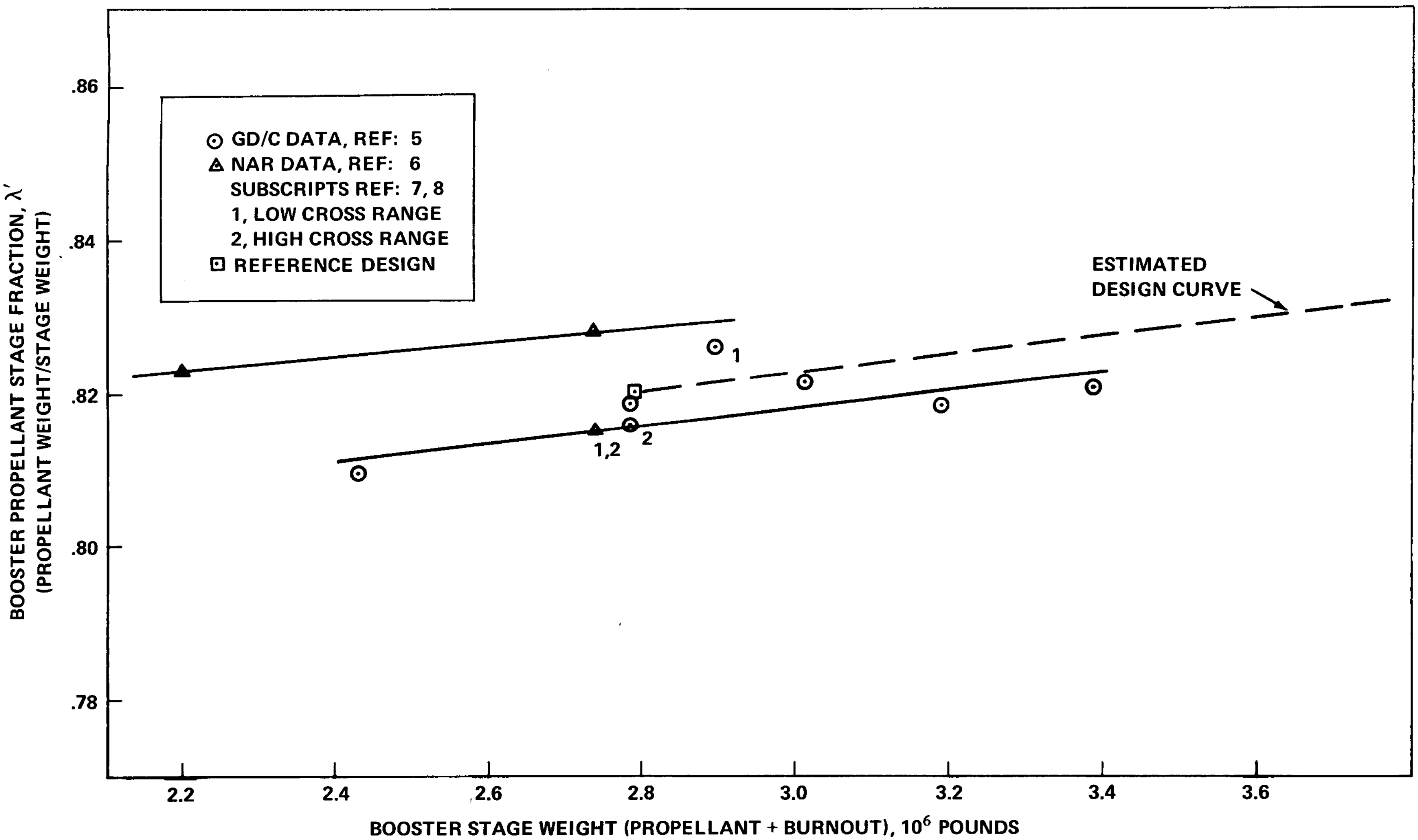

FIGURE 1 - SPACE SHUTTLE BOOSTER PROPELLANT STAGE FRACTION (λ') VS. STAGE WEIGHT CORRELATION

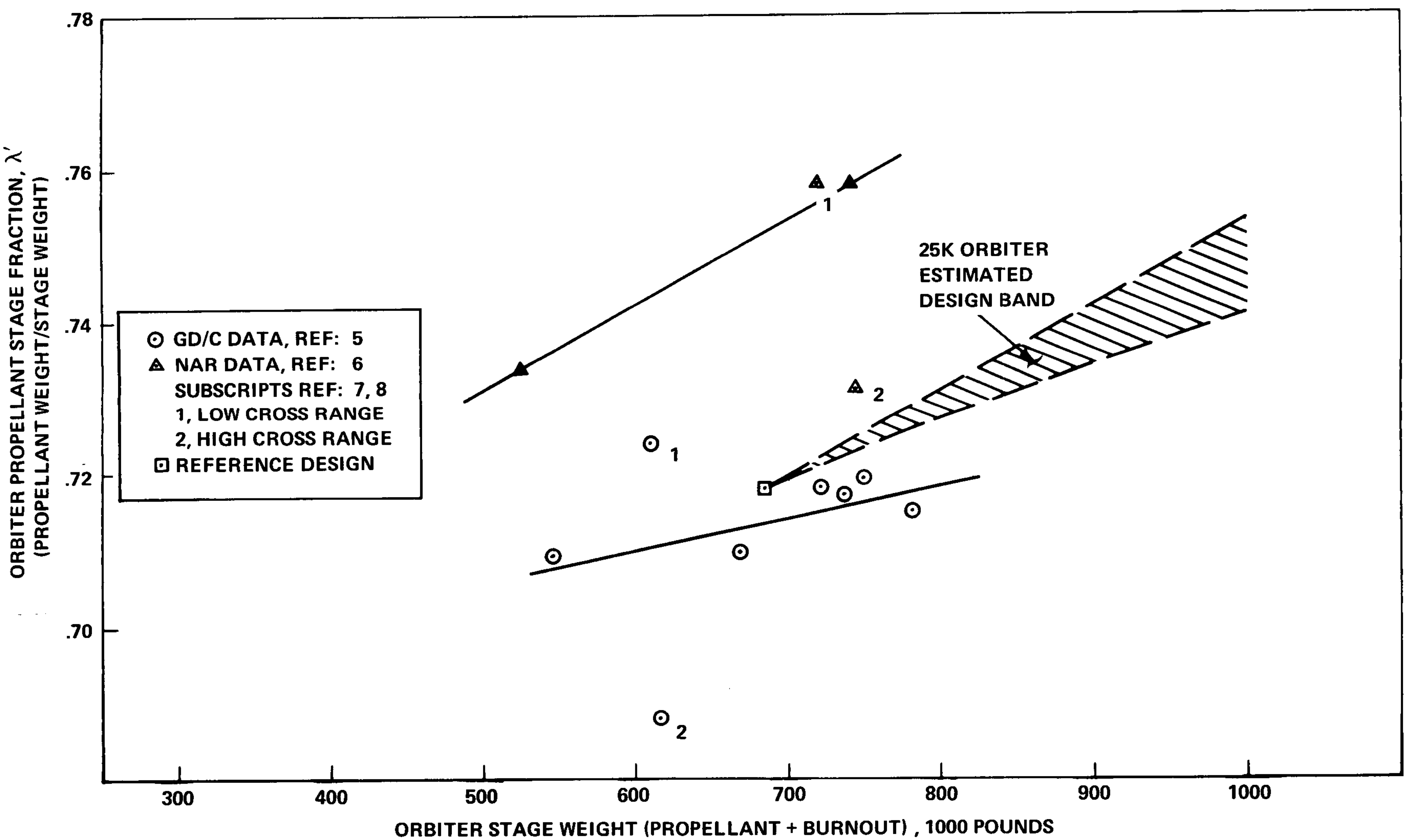

FIGURE 2 - SPACE SHUTTLE ORBITER PROPELLANT STAGE FRACTION (λ') VS STAGE WEIGHT CORRELATION FOR 15' x 60' PAYLOAD SIZE

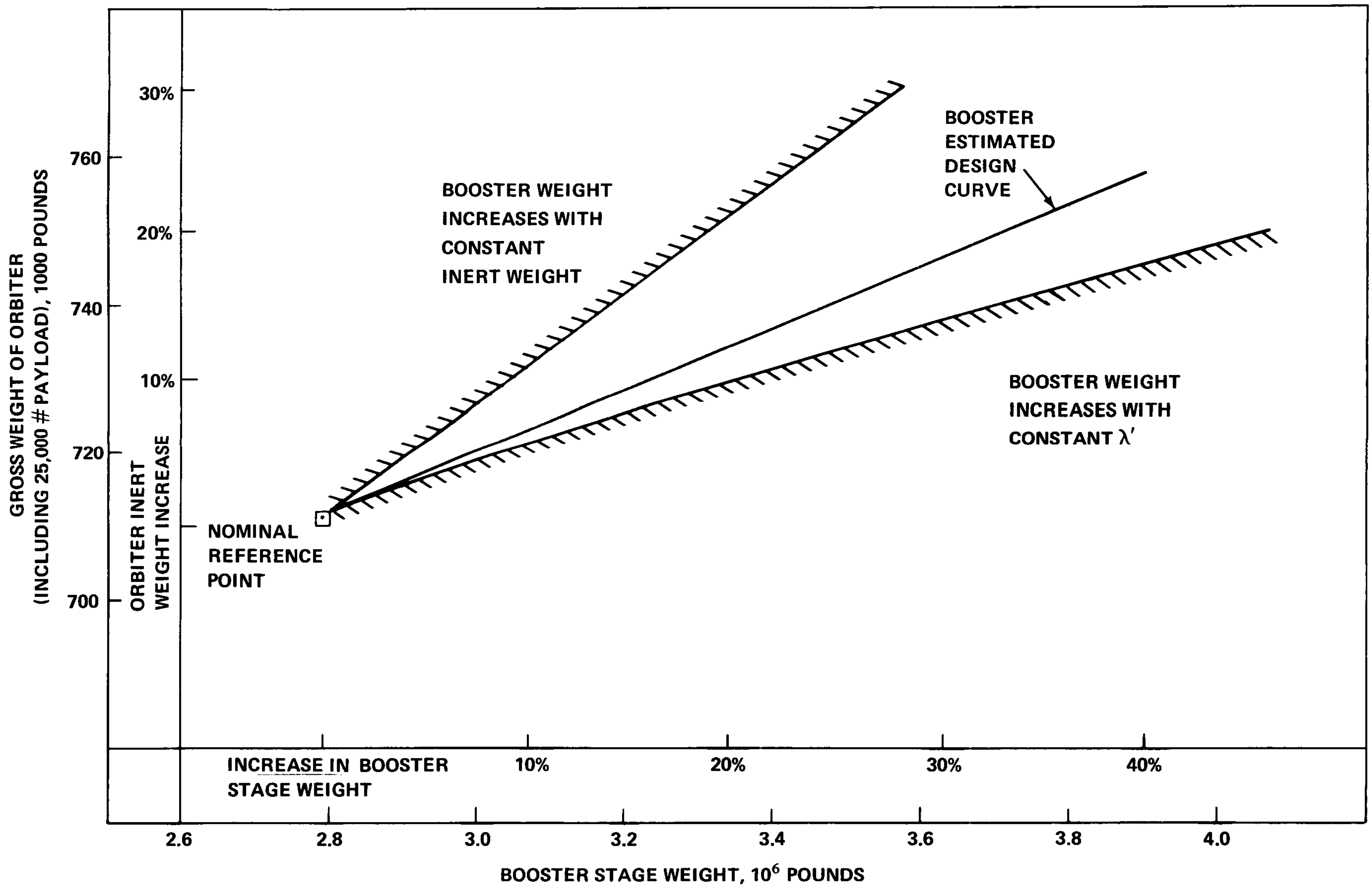

FIGURE 3 - ORBITER DEVELOPED FIRST: REQUIRED BOOSTER SIZED TO COMPENSATE FOR ORBITER INERT WEIGHT GROWTH

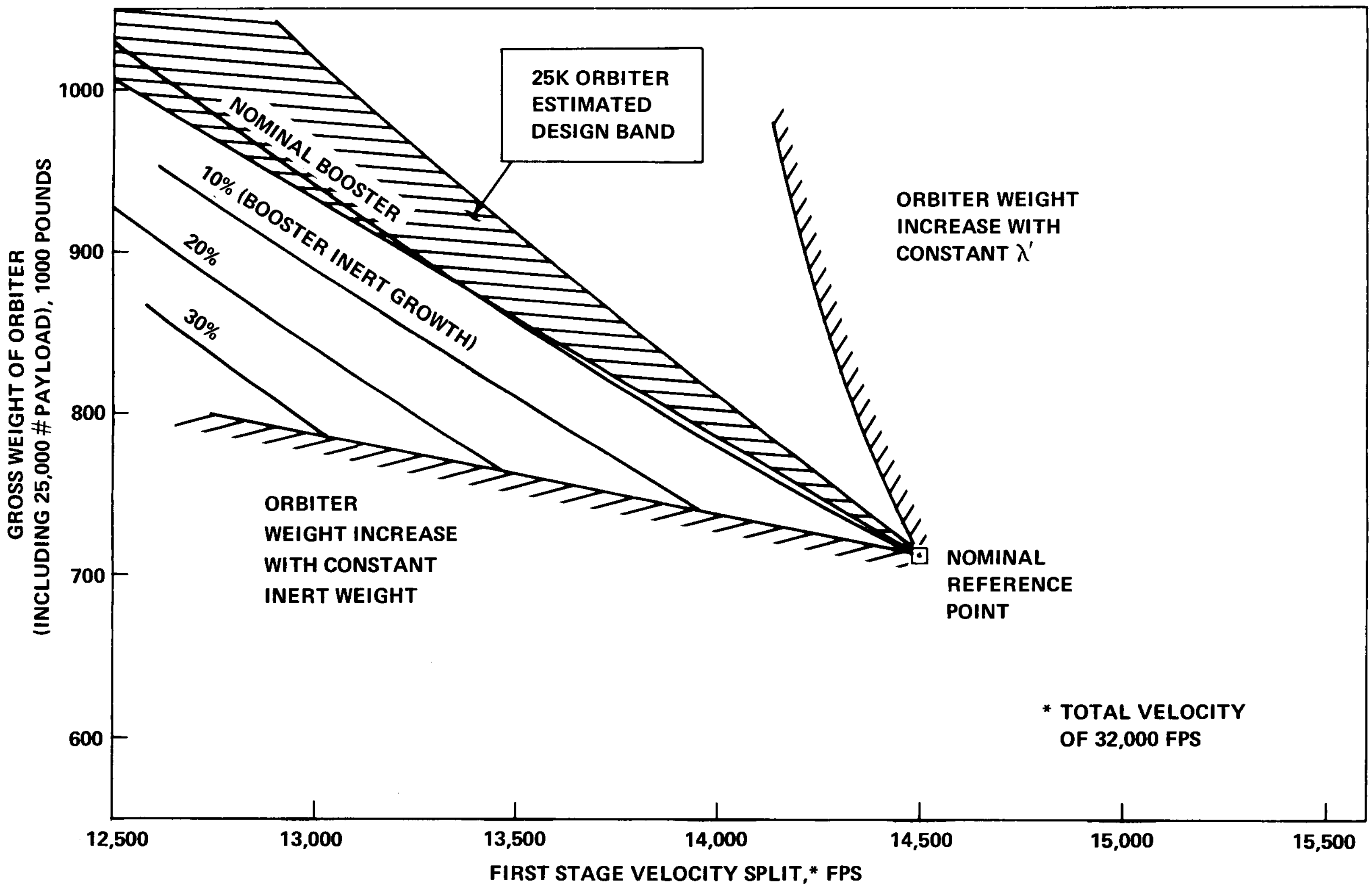

FIGURE 4 - BOOSTER DEVELOPED FIRST: REQUIRED ORBITER SIZED TO COMPENSATE FOR BOOSTER INERT WEIGHT.

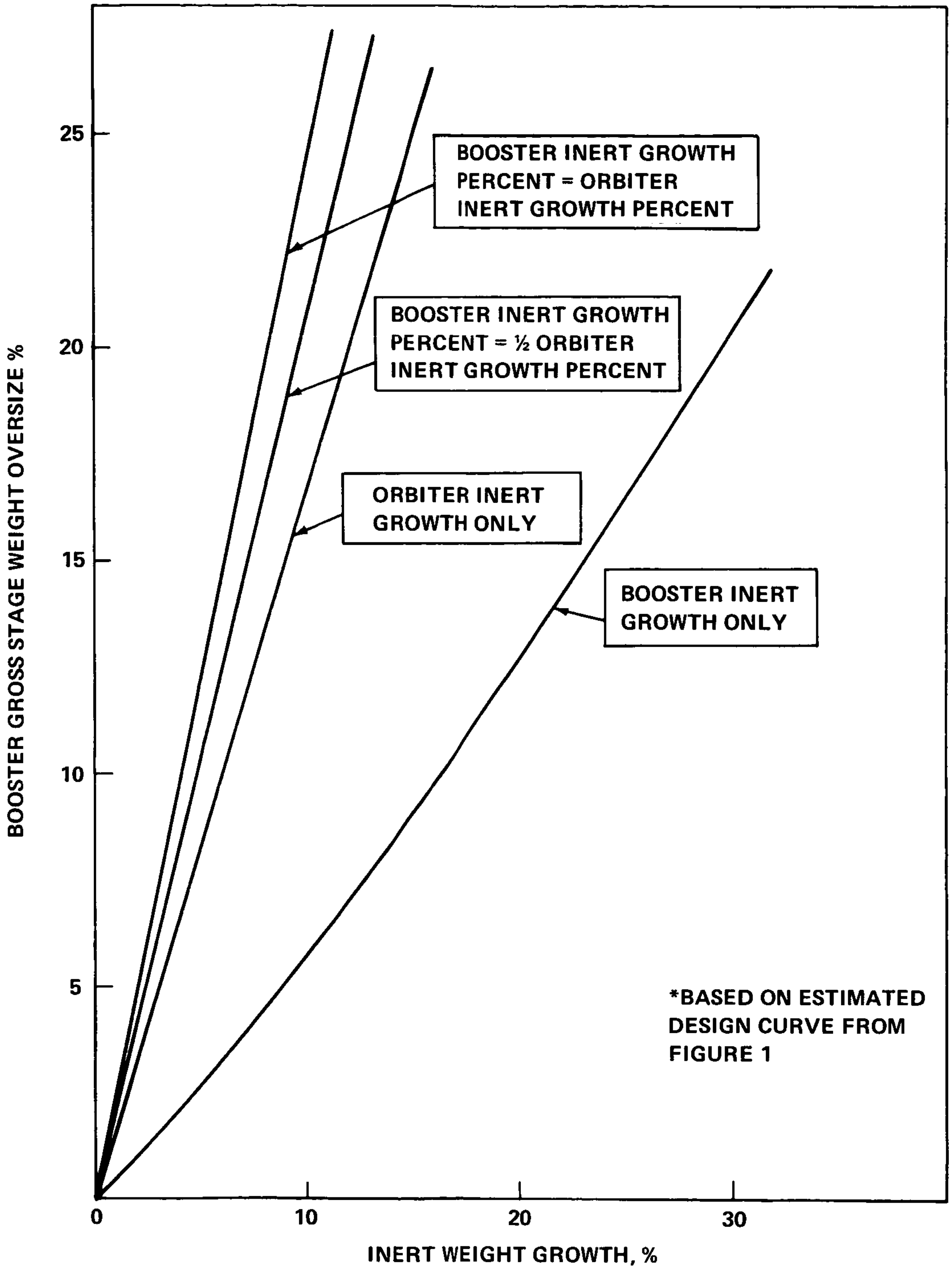

FIGURE 5 - BOOSTER OVERSIZE* NECESSARY TO COMPENSATE FOR ORBITER AND/OR BOOSTER INERT WEIGHT GROWTH